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M. BARA, S. KOHNOVÁ, J. SZOLGAY, L. GAÁL, K. HLAVČOVÁ

ASSESSING OF IDF CURVES FOR HYDROLOGICAL DESIGN BY SIMPLE SCALING OF 1-DAY PRECIPITATION TOTALS

Márta BARA
email: marta.bara@stuba.sk
Research field: Scaling of design precipitation
Silvia KOHNOVÁ
email: silvia.kohnova@stuba.sk
Research field: Design floods
Ján SZOLGAY
email: jan.szolgay@stuba.sk
Research field: Hydrological modelling
Ladislav GAÁL
email: ladislav.gaal@stuba.sk
Research field: Desing precipitation
Kamila HLAVČOVÁ
email: kamila.hlavcova@stuba.sk
Research field: Hydrological modelling

Address:
Department of Land and Water Resources Management,
Faculty of Civil Engineering,
Slovak University of Technology,
Radlinského 11, 813 68 Bratislava

ABSTRACT

In this paper the scaling properties of short term extreme rainfall in Slovakia were investigated. The simple scaling theory was applied to the intensity-duration-frequency (IDF) characteristics of a short duration rainfall. This method allows for the estimation of the design values of rainfall of selected recurrence intervals and durations shorter than a day by using only the daily data. The scaling behavior of rainfall intensities was examined, and the possibility of using simple scaling in Slovakia was verified. The methodology for the simple scaling of rainfall is demonstrated using an example of the meteorological station in Ilava.

KEY WORDS

- *IDF curves,*
- *simple scaling,*
- *hydrological planning*

INTRODUCTION

The intensity-duration-frequency (IDF) curves of rainfall are a very important tool for hydrological planning as they are used in the design and construction of different structures in water management, e.g., flood protection, sanitation networks, etc. IDF curves express the relation between the intensity, duration and periodicity (return period) of the rainfall. For the construction of IDF curves, a historical series of the maximum rainfall intensities at a higher time resolution (with a one-minute interval) is required. Such rainfall data are available only from a limited number of rain-gauging stations; the most accessible rainfall data are 1-day precipitation totals from a denser network of non-recording rain gauges. Simple scaling is a methodology that allows to use daily rainfall data to assess IDF characteristics for a short duration rainfall. By using the simple-scaling method, it is possible to estimate design precipitation values for arbitrary durations and selected return periods (e.g., Menabde, et al., 1999; Yu, et al., 2004). A considerable amount of studies have been devoted to extreme rainfall and its scaling properties. Theoretical results were published, e.g., by Burlando and Rosso (1996), Veneziano and Furcolo (2002), Langousis and Veneziano, (2007), Veneziano et al. (2007); more practically oriented results were reported, e.g., by Gupta and Waymire (1990), Menabde, et al. (1999), Yu, et al. (2004), Aronica and Freni (2005), Nhat et al. (2007), and Molnar and Burlando (2008).

In several previous studies (Bara, 2008, 2009; Bara, et al., 2008, 2009, 2010) the possibility of applying of the simple scaling method for assessing the design values of extreme rainfall in Slovakia was

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tested. In this paper the partial results from the above-mentioned works are summarized. Rainfall data from 56 meteorological stations from all over the territory of Slovakia were selected and analyzed. The primary rainfall data for the analysis consists of reconstructed rainfall intensities of 8 durations ranging from 5 to 180 minutes, respectively, which were taken from the historical dataset of Šamaj and Valovič (1973), and checked and preprocessed according to a methodology described in detail in Bara (2008). The historical dataset was extended by daily rainfall amounts taken from the data archive of the Slovak Hydrometeorological Institute (SHMI). The scaling exponents of the moments of rainfall intensities, the parameters of GEV and the quantiles of rainfall intensities were evaluated for all the stations analyzed. The IDF curves for different durations, and periodicities were derived, and the results given by different scaling exponents were compared.

INPUT DATA

For calculating the scaling exponents, rainfall data with a high temporal resolution from long observation periods are needed. Such rainfall data are not available from a sufficient number of rain-gauging stations in Slovakia. Therefore, a historical dataset of short-term rainfall intensities of durations from 5 up to 180 minutes derived by Šamaj and Valovič (1973) was taken for this study. Rainfall data from 56 stations were selected for the analysis. The historical quantile data were checked and preprocessed according to a methodology described in detail in Bara, et al. (2008) and Bara (2008). The dataset was completed by daily rainfall amounts, which were taken from the archives of the SHMI for the same observation period as in Šamaj and Valovič (1973). These daily data were not corrected for sliding durations (see, e.g., FEH, 1999). The quantiles of the 1-day (1440 min) precipitation durations for different periodicities were estimated using the GEV distribution function.
The locations of the analyzed stations is in Fig.1. The names of

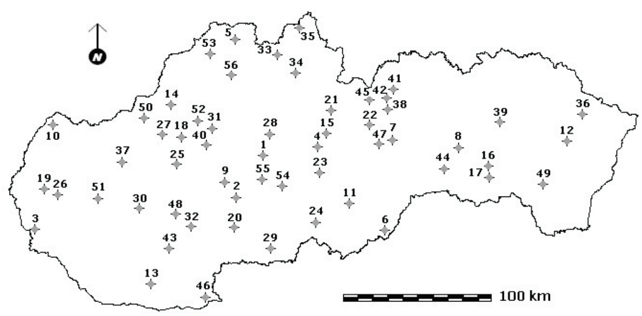

Fig. 1 *Location of the stations analyzed.*

Tab. 1 *List of the stations analyzed*

Nr.	Station	Record length	Years of observation
1	Banská Bystrica	18	1946-1954, 1957-1965
2	Banská Štiavnica	14	1952-1965
3	Bratislava VÚ	43	1922-1944, 1946-1965
4	Brezno	19	1946-1949, 1951-1965
5	Čadca	17	1949-1965
6	Číž	12	1954-1965
7	Dobšinská Ice Cave	21	1930-1948, 1950-1951
8	Gelnica	29	1935-1944, 1947-1965
9	Hliník n/Hronom	17	1949-1965
10	Holíč	18	1946-1949, 1951-1961, 1963-1965
11	Hrachovo	15	1945-1949, 1951-1960
12	Humenné	24	1937-1943,1947-1948, 1951-1965
13	Hurbanovo	64	1901-1938, 1940-1965
14	Ilava	22	1944-1965
15	Jarabá	32	1924-1930, 1932-1944, 1947-1952, 1960-1965
16	Košice - Bankov	13	1923-1935
17	Košice - airport	20	1946-1965
18	Kšinná	12	1931-1940, 1943-1944
19	Kuchyňa Nový Dvor	21	1934-1937, 1946-1949, 1951-1955, 1958-1965
20	Ladzany	16	1950-1965
21	Liptovsky Hrádok	32	1931-1944, 1948-1965
22	Liptovská Teplička	19	1925-1930, 1932-1944
23	Lom nad Rimavicou	27	1924-1926, 1929-1944, 1946-1953
24	Lučenec	28	1931-1938, 1946-1965
25	Malé Bielice	13	1948-1949, 1955-1965
26	Modra - Pánsky dom	20	1925-1939, 1941-1944, 1946
27	Motešice - Letný dvor	14	1931-1944
28	Motičky	18	1946, 1948-1955, 1957-1965
29	Nenince	16	1950-1965

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Tab. 1 *List of the stations analyzed*

Nr.	Station	Record length	Years of observation
30	Nitra	21	1933-1943, 1949-1951, 1959-1965
31	Nitrianske Pravno	17	1925-1941
32	Nový Tekov	13	1952-1955, 1957-1965
33	Oravská Lesná	16	1944, 1946-1949, 1952-1954, 1956-1957, 1960-1965
34	Oravský Podzámok	14	1944-1948, 1951, 1953, 1955, 1957-1962
35	Oravská Polhora	23	1930-1952
36	Papín	13	1923-1929, 1933-1938
37	Piešťany	13	1949, 1951-1959, 1963-1965
38	Poprad - airport	20	1946-1965
39	Prešov - airport	18	1946-1956, 1959-1965
40	Prievidza	14	1951-1961, 1963-1965
41	Skalnaté Pleso	17	1944-1960
42	Starý Smokovec	43	1923-1965
43	Svätuša (Podhájska)	12	1953-1964
44	Štós	24	1929-1937, 1950, 1952-1965
45	Štrbské Pleso	41	1922-1944, 1948-1965
46	Štúrovo	17	1949-1965
47	Švermovo (Telgárt)	14	1947-1951, 1957-1965
48	Tesárske Mlyňany	14	1951-1965
49	Trebišov	16	1949-1963, 1965
50	Trenčianske Biskupice	12	1940-1943, 1946-1952, 1955
51	Trnava	22	1930-1952
52	Valašská Belá	16	1949, 1951-1965
53	Veľké Rovné - Podivor	27	1935-1938, 1940-1944, 1946-1953, 1956-1965
54	Víglaš - Pstruša	16	1949-1958, 1960-1965
55	Zvolen (+ Sliač)	32	1927-1941, 1943, 1947-1957, 1962-1966
56	Žilina	19	1946-1949, 1951-1965

the stations corresponding to Fig.1, the periods of observation and the number of years observed for each station are listed in Tab. 1. Generally, the periods of observation range from the 1930s to the 1960s, and the average length of observation is approximately 20 years.

For demonstrating the methodology of the simple scaling of rainfall, the Ilava station was selected. Ilava is situated in Western Slovakia at an altitude of 225 m a.s.l., with 22 years of observation data available from the period 1944 – 1965.

THE SIMPLE SCALING METHOD

The scaling property of rainfall intensity I for a duration d can be expressed by the following relationship (e.g., Menabde, 1999; Yu, 2004)

$$I_d = (d/D)^{-\beta} I_D \tag{1}$$

where β is the scaling exponent, and I_D is the rainfall intensity for duration D. The ratio d/D is the scaling ratio between the known (measured or estimated) duration of the rainfall intensities and the desired durations of the design rainfall intensities. Such behavior is denoted as 'simple scaling in the strict sense'(Gupta and Waymire, 1990).

This type of scaling implies that both variables have the same probability distribution function if finite moments of an order q exist for both. This again implies that their moments are equal. The relationship between the q^{th} moments of rainfall intensity can be obtained after raising both sides of Eq. (1) to the power q and taking the ensemble's average (Menabde, et al., 1999; Yu, et al., 2004):

$$E\left[I_d^q\right] = (d/D)^{-\beta_q} E\left[I_D^q\right] \tag{2}$$

where β_q represents the scaling exponent of order q. The scaling exponent can be estimated from the slope of the linear regression relationships between the log-transformed values of the moments and scale parameters for various orders of moments. The case when the relationship between the scaling exponents and the order of moments is linear is referred to as 'wide sense simple scaling' (Gupta and Waymire, 1990).

The scaling behavior can also be found for the parameters of a fitted cumulative distribution function (CDF) (Menabde, et al., 1999; Yu, et al., 2004). For the simple scaling process it can be shown that the statistical properties of the CDF for two different timescales d and D are related as follows (Menabde, et al., 1999; Yu, et al., 2004):

$$\mu_d = (d/D)^{-\beta} \mu_D \tag{3}$$

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$$\sigma_d = (d/D)^{-\beta}\sigma_D \tag{4}$$

where μ_d (σ_d) is the location (scale) parameter of an annual maximum rainfall depth series of duration d; (d/D) denotes the scale ratio; and β is the scaling exponent.

The scaling hypothesis also holds for the quantiles of the maximum rainfall intensity estimated from the CDF. The intensities of events with the same return period T, but a different duration d, will satisfy the scaling relation (Menabde, et al., 1999; Yu, et al., 2004):

$$I_d(T) = (d/D)^{-\beta} I_D(T) \tag{5}$$

Based on Eq. (5), it is possible to estimate the scaling exponent even if the data record is short (Menabde, et al., 1999; Yu, et al., 2004).

The process of assessing the scaling exponents of the moments of rainfall intensities, the quantiles of rainfall intensities, and the scaling exponents of the parameters of the CDF of rainfall intensities is demonstrated on the example of the Ilava station (Figs. 2 – 4).

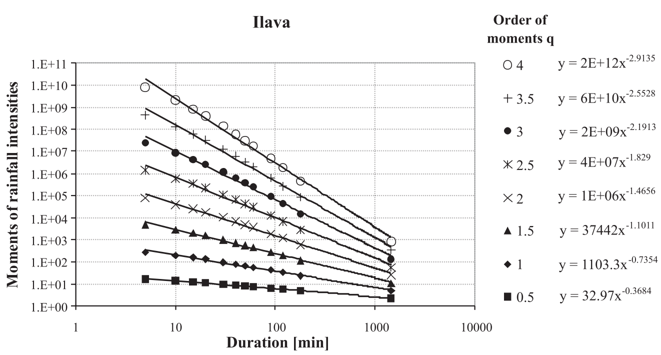

Fig. 2 *Scaling of the moments of rainfall intensities*

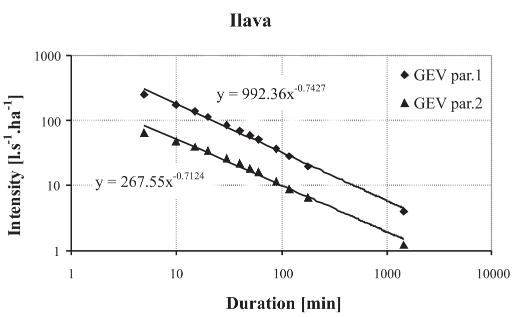

Fig. 3 *Scaling of the parameters of the CDF of rainfall intensities*

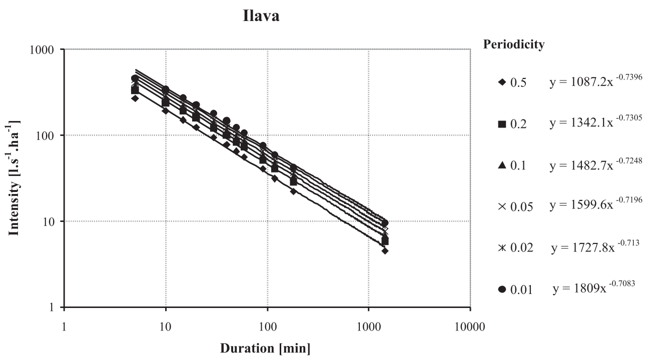

Fig. 4 *Scaling of the quantiles of rainfall intensities*

Following the above described process the scaling exponents of the q^{th} moments of rainfall intensities (q = 0.5; 1; 1.5; 2; 2.5; 3; 3.5; 4), the scaling exponents of the parameters of the CDF of rainfall intensities and the scaling exponents of the quantiles of rainfall intensities for periodicities P = 5; 2; 1; 0.5; 0.2; 0.1; 0.05; 0.02; 0.01 (i.e. for return periods T = 0.2; 0.5; 1; 2; 5; 10; 20; 50; 100 years) were derived for all the stations analyzed. For scaling the parameters of the CDF, the GEV probability distribution was chosen, and the scaling exponents of the 1st and 2nd parameters of the GEV were derived.

All the scaling exponents (derived by all the mentioned approaches) vary from 0.6175 to 0.8434, and the average value is 0.7356. The scaling exponents of the moments of rainfall intensities vary from 0.6350 to 0.7978, with an average of 0.7364. The values of the scaling exponents of the 1st and 2nd parameters of GEV have a range from 0.6424 to 0.8102 and from 0.6175 to 0.8434, respectively. The average value in the case of the 1st parameter of the GEV is 0.7552 and in the case of the 2nd parameter, the average is 0.7231. The scaling exponents of the quantiles of the rainfall intensities vary from 0.6302 to 0.8203, with an average value of 0.7279. The statistics described of all derived scaling exponents are summarized in Table 2.

Tab. 2 *Minimum, maximum and average scaling exponents in the analyzed stations*

Scaling exponents of	moments	1st parameter of GEV	2nd parameter of GEV	quantiles
minimum	0.6350	0.6424	0.6175	0.6302
maximum	0.7978	0.8102	0.8434	0.8203
average	0.7364	0.7552	0.7231	0.7279

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ASSESSING THE IDF CURVES BY SCALING THE 1-DAY PRECIPITATION TOTALS

By using the simple scaling method, it is possible to derive the IDF curves of rainfall intensities from the daily rainfall data for selected durations and recurrence intervals. For testing the scaling methodology, 5 sample stations were selected: Hurbanovo, Košice – Bankov, Košice - airport, Liptovský Hrádok and Štrbské Pleso. Using the derived scaling exponents (scaling exponents of the moments and quantiles of the rainfall intensities, and the scaling exponents of the 1st parameter of the GEV) the 1-day precipitation totals were downscaled at the test stations, and the design values of rainfall for durations *d* = 5, 10, 15, 20, 30, 40, 50, 60, 90, 120 and 180 minutes were estimated for selected periodicities (depending on the length of the observations at each station analyzed).

The estimated design values of the rainfall intensities decrease from the smallest periodicity and the shortest duration (5 min) to higher periodicities and longer durations. Such behavior is typical of such data, which indicates that the simple scaling method can be suitable for assessing IDF curves in Slovakia. As an example, the IDF curves for periodicities 1, 0.5, 0.2, 0.05, 0.02 and 0.01 at the Hurbanovo station are displayed in Fig.5.

The downscaled values of the design rainfall were compared to the results of Šamaj and Valovič (1973). The relative deviations

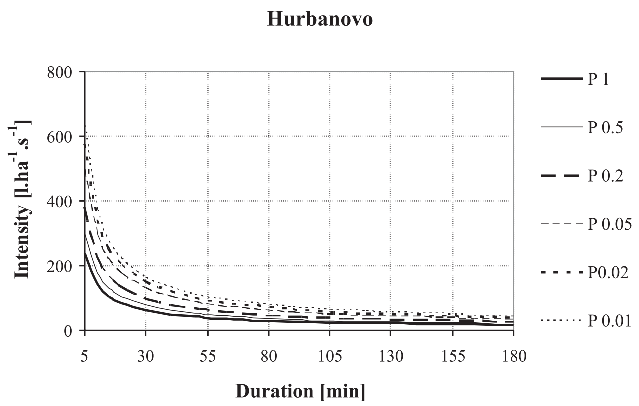

Fig. 5 *The IDF curves of rainfall assessed by downscaling at the Hurbanovo station*

in percentages were calculated between the downscaled and the reference IDF curves (Šamaj and Valovič, 1973) using the following relationship:

$$\left| RO = \frac{x-y}{y}.100 \right| \quad [\%] \,, \tag{6}$$

where results are given in absolute value; *x* are the design values determined by the downscaling, and *y* are the design values assessed by Šamaj and Valovič (1973).

In average, the smallest deviations between the downscaled and reference data occured in the case of scaling by the scaling exponents of the 1st parameter of the GEV; however, the maximum deviations also occurred for these scaling exponents. The best results appeared at the Hurbanovo station, where the longest observation period was available.

In Tab. 3 the minimum, maximum and average relative deviations in each analyzed station are listed separately and also the total average values of these statistics for all the analyzed stations. The average relative deviation was 13%, and the maximum deviations amounted to 46% on average. In general, the downscaled design values of the precipitation are underestimated in comparison to the design values assessed by Šamaj & Valovič (1973) for lower periodicities and longer durations of rainfall intensities, but not in all the analyzed cases.

Furthermore, the sensitivity of the downscaled IDF curves depending on the values of the scaling exponents was analyzed. It was shown that if the value of the scaling exponents changes by 0.1, the downscaled design precipitation values change by 40% on average. This means that it is not possible to use one scaling exponent for the whole territory of Slovakia. For smaller areas regional scaling exponents can be derived.

CONCLUSIONS

The aim of this study was to analyze the scaling properties of short-term rainfall in Slovakia. The scaling parameters of the moments of rainfall intensities, the quantiles of rainfall intensities and the scaling exponents of the parameters of the GEV were derived for 56 selected meteorological stations. The IDF curves of the rainfall

Tab. 3 *The minimum, maximum and average relative deviations in the analyzed stations*

	Hurbanovo	Košice - Bankov	Košice - airport	Liptovský Hrádok	Štrbské Pleso	Total average
minimum	0.01	0.43	0.04	0.04	0.03	0.11
maximum	24.68	39.83	81.49	50.45	31.53	45.60
average	6.29	19.28	15.07	10.88	12.31	12.77

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intensities for the selected durations and recurrence intervals were estimated using a simple scaling methodology. The advantage of the simple scaling method is that it allows for the estimation of the design values of rainfall intensity for arbitrary durations using only commonly available daily rainfall data.

The downscaled IDF curves were compared to those assessed by Šamaj and Valovič (1973). The relative deviations in percentages were calculated. The sensitivity of the downscaled IDF curves depending on the values of the scaling exponents was analyzed. The results of the study showed that the analyzed data have a simple scaling property and that the simple scaling method is suitable for assessing IDF curves for practical application in Slovakia.

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